NASA/TM—2000–209891, Vol. 162

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Andrea Papagno, Editors

Volume 162

BOREAS TE-10 Leaf Optical Properties

Stephen S. Chan and Elizabeth Middleton, NASA Goddard Space Flight Center, Greenbelt, Maryland

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

October 2000

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A10

BOREAS TE-10 Leaf Optical Properties

Stephen S. Chan, Elizabeth Middleton

Summary

The BOREAS TE-10 team collected several data sets in support of its efforts to characterize and interpret information on the reflectance, transmittance, gas exchange, oxygen evolution, and biochemical properties of boreal vegetation. This data set describes the spectral optical properties (reflectance and transmittance) of boreal forest conifers and broadleaf tree leaves as measured with a Spectron Engineering SE590 spectroradiometer at the SSA OBS, OJP, YJP, OA, OA-AUX, YA-AUX, and YA sites. The data were collected during the growing seasons of 1994 and 1996 and are stored in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS TE-10 Leaf Optical Properties

1.2 Data Set Introduction

This data set describes the spectral optical properties (reflectance and transmittance) of included leaves and needles from boreal forest tree species as measured with a Spectron Engineering SE590 spectroradiometer at the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA) Old Black Spruce (OBS), Old Jack Pine (OJP), Young Jack Pine (YJP), Old Aspen (OA), Old Aspen Auxiliary (OA-AUX), Young Aspen Auxiliary (YA-AUX), and Young Aspen (YA) sites.

1.3 Objective/Purpose

The purposes of this work were to:

- Obtain a canopy profile of needle spectral optical properties.
- Examine interspecific and interseasonal differences in these parameters.
- Correlate physiological processes at the leaf/needle level with optical measurements amenable to remote sensing.
- Examine the relationships between the physiological parameters, especially photosynthesis and conductance rates, and the optical parameters (fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and spectral vegetation indices (SVI)).
- Parameterize the canopy-level radiative transfer and physiological models utilized in landscape analyses by other investigators.

1.4 Summary of Parameters and Variables

Hemispherical reflectance (R) and transmittance (T) factors were measured for needles of various growth years and individual leaves illuminated at near-normal incidence measured using an external light source and LI-COR LI-1800-12 integrating sphere attached to a Spectron Engineering SE590 spectroradiometer.

1.5 Discussion

Hemispherical reflectance and transmittance factors of individual needles (ages: current year, previous year, 2 years ago, and up to 5 years ago growth) and broadleaf tree leaves (current year) were measured using a LI-COR LI-1800-12 Integrating Sphere attached to a Spectron Engineering SE590 spectroradiometer, and the image analysis system. The SSA sites studied were OBS, OJP, YJP, OA, OA-AUX, YA-AUX, and YA.

1.6 Related Data Sets

BOREAS TE-10 Gas Exchange Data
BOREAS TE-12 Leaf Optical Data for SSA Species

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Elizabeth Middleton
Project Scientist

Dr. Joseph Sullivan
Assistant Professor

2.2 Title of Investigation

CO_2 and Water Fluxes in the Boreal Forest Overstory: Relationship to fAPAR and Vegetation Indices for Needles/Leaves

2.3 Contact Information

Contact 1:

Stephen S. Chan
Biospheric Sciences Branch, Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-2386
sailun@ltpmail.gsfc.nasa.gov

Contact 2:
Dr. Elizabeth Middleton
Biospheric Sciences Branch, Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-8344
(301) 286-0239 (fax)
betsym@ltpmail.gsfc.nasa.gov

Contact 3:
Andrea Papagno
Raytheon ITSS
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-3134
(301) 286-0239 (fax)
Andrea.Papagno@gsfc.nasa.gov

Contact 4:
Shelaine Curd
Raytheon ITSS
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-2447
(301) 286-0239 (fax)
Shelaine.Curd@gsfc.nasa.gov

3. Theory of Measurements

Leaves, needles, and bark are canopy elements that are important in scattering radiation in boreal forest vegetation (Norman and Jarvis, 1974). Needle and bark properties can vary considerably depending on age and height in the canopy; elements deep in the canopy may be covered with algae and fungi, and shade-induced effects on shoot development may exist (Norman and Jarvis, 1974; Smith and Carter, 1988). In the near-infrared portion of the electromagnetic spectrum, little radiation is absorbed; thus, scattering by canopy elements will be significant. In contrast, leaves and needles absorb a large portion of PAR (Daughtry et al., 1989; Williams, 1991). Conifer needles absorb more PAR than deciduous leaves; twigs, especially the current year's growth, also absorb PAR (Williams, 1991). Thus, the scattering component of PAR may be small except in sparse canopies with high underlying surface albedo.

4. Equipment

4.1 Sensor/Instrument Description

The Spectron Engineering SE590 is a portable battery-operated spectroradiometer consisting of a CE500 data analyzer/logger controller, CE390 spectral detector head, and an external battery charger/power supply. The CE500 is a self-contained microprocessor-based controller that processes the signal from the detector head, amplifying and digitizing it with 12-bit resolution. For each spectral scan, the controller actuates the CE390 shutter, measures and stores the dark current, calculates optimum integration time, acquires the spectrum, and automatically subtracts the noise for all 256 spectral elements. Each scan was recorded individually. The entire 12-bit binary spectrum is stored in a double-precision register until it is transmitted through the RS-232C port. The spectral detector head uses a diffraction grating as the dispersive element; the spectrum is imaged onto a 256-element photodiode array. Each element integrates simultaneously, acquiring the spectrum in a fraction of a second. The interconnect cable from the spectral head to the controller couples the spectral signals to the controller and the timing and control signals to the detector head. A shutter in the detector head, operated by the controller, closes the light path for dark current measurements. For further information, consult the SE590 operating manual. The serial numbers for the SE590s used in 1994 and 1996 are 2071 and 1051, respectively.

The LI-COR LI-1800-12 integrating sphere is an instrument for collecting radiation that has been reflected from or transmitted through a sample material. An external light source illuminates a spot on the sample. A standard light source (11.4-mm diameter) and a modified light source that restricts the illumination spot size (3.5-mm x 11-mm) were used. The lamp used in the external light source is a 6-Volt 10-Watt glass-halogen. For a further description, see the LI-COR Integrating Sphere Instruction Manual. Serial Number 2071 was used in 1994, and 1051 was used in 1996.

An image analysis system was used to measure the gaps between sample elements (e.g., needles) when a sample did not fill the entire integrating sphere sample port or a single sample element was too narrow to be completely encompassed by the modified light source.

The image analysis system included a black-and-white (B/W) charge-coupled device (CCD) video camera, a monochrome frame-grabber board, an IBM PC-compatible laptop unit with docking station, a light table, and a video monitor display with full 640 x 480 pixel spatial resolution and 256 gray levels. This system was used to determine gap fraction per sample, defined as the ratio of needle gap area to that of the total illuminated area within the aperture (round or slitted) of a precision reference template placed on a light table as viewed from above by the camera. The template, a small metal disk, was viewed alone and the area measured. Then the template was viewed with the sample on top of it and the area left uncovered by the needles was measured. The ratio of the gap area to total area makes the gap fraction. Software for image capture was "Computer Eyes/RT" (Digital Vision, Inc., Dedham, MA) and for processing was "Mocha" (SPSS, Inc., Chicago, IL). Appropriate calibration procedures were used: a) for the area of a standard template, each sample; b) for the stray light/dark current scans per measurement set; and c) for the wavelength stability of the radiometer and its spectral radiance coefficients.

A monochrome frame-grabber board (UM-08128-B) was used to input the signal from the camera into an IBM-compatible laptop computer with a docking station. SPSS Inc.'s software Mocha ver. 2.0 was used to measure the areas of the incident light source beams and gaps. The display monitor was an IBM VGA with 640- by 480-pixel resolution.

4.1.1 Collection Environment

The vertical profile of the canopy was divided into three layers: top, middle, and bottom. Measurements were taken at the SSA OBS (Picea mariana), OJP (Pinus banksiana and Apocynum androsaemifolium), YJP (Pinus banksiana), YA (Populus tremuloides and Corylus cornuta Marsh), OA (Populus tremuloides and Corylus cornuta Marsh), OA-AUX (Populus tremuloides and Corylus cornuta Marsh), and YA-AUX (Populus tremuloides and Corylus cornuta Marsh and Picea glauca). At the OBS, OA, OA-AUX, and OJP sites, sample collection was made from canopy access towers constructed onsite by BOREAS staff. At the YJP, YA, and YA-AUX sites, collection was accomplished from the ground. Collection of hazelnut understory was also accomplished from the ground. In 1994, data were obtained during three discrete measurement periods (1 to 2 days each period) designated by BOREAS as Intensive Field Campaigns (IFCs) (IFC-1, -2, -3). In 1994, these IFCs were selected to measure parameters at bud breaks and leaf expansion (24-May to 12-Jun), during midsummer or peak growing season (26-Jul to 08-Aug) and at the onset of dormancy or senescence in autumn (30-Aug to 15-Sep). In 1996, collection dates did not necessarily coincide with any official IFCs. In 1994, the samples were measured individually. The period of measurement in 1996 was during July. On collection/observation day 14-Jul-1996, the 1992 and 1993 samples were combined and the 1994 and 1995 samples were combined. Branch tips measured were excised from the trees and sealed in plastic bags with moist towels. After collection, samples were refrigerated until the measurements were conducted in the room-temperature field laboratory.

4.1.2 Source/Platform

During these measurements, the spectroradiometer and the integrating sphere were mounted on a tripod in the laboratory.

4.1.3 Source/Platform Mission Objectives

Not applicable.

4.1.4 Key Variables

Adaxial and abaxial spectral reflectance and transmittance. For both broadleaves and conifer needles, the designation of foliar surfaces as either adaxial (dorsal or upper) or abaxial (ventral or underside) is made on an anatomical basis (Esau, 1977). For broadleaves (both dicots and monocots), the adaxial (dorsal) surface is the one adjacent to the palisade mesophyll layer, and the abaxial (ventral) surface is adjacent to the spongy mesophyll layer. For conifers, the adaxial surface is the flat (or less curved) facet whose surface lies closest to the xylem at the needle core, while the abaxial surface is the typically more curved and opposite facet whose surface lies closest to the phloem at the needle core.

4.1.5 Principles of Operation

The SE590 spectral detector head uses a diffraction grating as the dispersive element; the spectrum is imaged onto a 256-element photodiode array. Each element integrates simultaneously, acquiring the spectrum in a fraction of a second.

The LI-COR LI-1800-12 integrating sphere is an external integrating sphere, which means that the sample is external to the sphere; when the sample is in place, a small part of the sample actually makes up part of the sphere wall. For further information, see the LI-COR 1800-12 Integrating Sphere Instruction Manual.

The CCD camera transmits a signal to the frame-grabber board, which translates the intensity of each pixel to a gray scale from 0 (black) to 255 (white) levels. The Mocha software program was set up to count the number of pixels in a defined area of interest for a range of gray scales that represent the "white" gaps between the sample elements. The white threshold was determined by adjusting the threshold so that a standard size (area) reference template actually registered the correct area.

4.1.6 Sensor/Instrument Measurement Geometry

All instrumentation took place under laboratory conditions. The SE590 was mounted on top of the LI-COR LI-1800-12 integrating sphere. A tripod was attached to the support connecting the SE590 and integrating sphere. A modified external light source with a slitted beam (3.5 mm x 11 mm) was used to illuminate narrow samples and associated reference. A standard external light source with a circular beam (11.4-mm diameter spot size) was used to illuminate all other samples and associated reference. The light source was kept in a horizontal position according to integrating sphere manual requirements.

4.1.7 Manufacturer of Sensor/Instrument

Spectron Engineering SE590 Spectroradiometer:
Spectron Engineering, Inc.
25 Yuma Court
Denver, CO 80223
(303) 733-1060

LI-COR LI-1800-12 Integrating Sphere:
LI-COR, Inc.
Box 4425
Lincoln, NE 68504
(402) 467-3567

B/W CCD WVBL200 Video Camera
Panasonic

MOCHA Software (ver. 2.0):
SPSS, Inc.
233 S. Wacker Drive
11th Floor
Chicago, IL 60606-6307
1 (800) 543-2185
1 (800) 841-0064 (fax)

4.2 Calibration

Appropriate calibration procedures were used: a) for the area of a standard template, each sample; b) for the stray light/dark current scans per measurement set; and c) for the wavelength stability of the radiometer and its spectral radiance coefficients.

4.2.1 Specifications

Each SE590 has a unique wavelength associated with each of its 252 bands. A cubic spline interpolation was applied to the 252 bands to standardize the wavelengths to every 5 nm from 400 to 1000 nm, so that wavelength-to-wavelength comparisons can be made among SE590s.

4.2.1.1 Tolerance

None given.

4.2.2 Frequency of Calibration

The SE590s were calibrated against Hg and Ar vapor lamps before and after each IFC or collection session.

4.2.3 Other Calibration Information

For 1994: Wavelengths, in nanometers, and their corresponding channels (ch), used for data reduction. Wavelength Characterization (nm) for BOREAS Terrestrial Ecology (TE)-10 SE590 on 31-May-1994 by NASA GSFC (SE590 serial number 2071):

channel	wavelength	ch.	wavelength	ch.	wavelength	ch.	wavelength
1	359.6461	64	534.7401	127	721.4871	190	919.8871
2	362.3343	65	537.6133	128	724.5453	191	923.1302
3	365.0255	66	540.4895	129	727.6064	192	926.3763
4	367.7196	67	543.3686	130	730.6705	193	929.6253
5	370.4167	68	546.2506	131	733.7374	194	932.8773
6	373.1167	69	549.1355	132	736.8074	195	936.1322
7	375.8196	70	552.0235	133	739.8803	196	939.39
8	378.5255	71	554.9143	134	742.9561	197	942.6508
9	381.2343	72	557.8081	135	746.0348	198	945.9145
10	383.9461	73	560.7048	136	749.1165	199	949.1812
11	386.6607	74	563.6044	137	752.2011	200	952.4508
12	389.3783	75	566.507	138	755.2886	201	955.7233
13	392.0989	76	569.4125	139	758.3791	202	958.9937
14	394.8224	77	572.321	140	761.4726	203	962.2771
15	397.5488	78	575.2324	141	764.5689	204	965.5584
16	400.2782	79	578.1467	142	767.6682	205	968.8427
17	403.0105	80	581.064	143	770.7704	206	972.1299
18	405.7457	81	583.9841	144	773.8756	207	975.42
19	408.4838	82	586.9073	145	776.9837	208	978.7131
20	411.225	83	589.8334	146	780.0947	209	982.0091
21	413.969	84	592.7624	147	783.2087	210	985.3081

22	416.716	85	595.6943	148	786.3256	211	988.6099
23	419.4659	86	598.6292	149	789.4455	212	991.9147
24	422.2187	87	601.567	150	792.5683	213	995.2225
25	424.9745	88	604.5077	151	795.694	214	998.5332
26	427.7332	89	607.4514	152	798.8226	215	1001.846
27	430.4949	90	610.3981	153	801.9542	216	1005.163
28	433.2595	91	613.3476	154	805.0887	217	1008.482
29	436.027	92	616.3001	155	808.2262	218	1011.805
30	438.7975	93	619.2555	156	811.3666	219	1015.13
31	441.5708	94	622.2139	157	814.5099	220	1018.459
32	444.3472	95	625.1752	158	817.6562	221	1021.79
33	447.1265	96	628.1394	159	820.8054	222	1025.124
34	449.9087	97	631.1066	160	823.9576	223	1028.461
35	452.6938	98	634.0767	161	827.1126	224	1031.801
36	455.4819	99	637.0498	162	830.2706	225	1035.144
37	458.2729	100	640.0258	163	833.4316	226	1038.49
38	461.0668	101	643.0047	164	836.5955	227	1041.839
39	463.8637	102	645.9865	165	839.7623	228	1045.191
40	466.6636	103	648.9713	166	842.9321	229	1048.545
41	469.4663	104	651.959	167	846.1048	230	1051.903
42	472.272	105	654.9497	168	849.2804	231	1055.264
43	475.0806	106	657.9433	169	852.4589	232	1058.627
44	477.8922	107	660.9398	170	855.6405	233	1061.994
45	480.7067	108	663.9393	171	858.8249	234	1065.363
46	483.5241	109	666.9417	172	862.0123	235	1068.735
47	486.3445	110	669.9471	173	865.2026	236	1072.111
48	489.1678	111	672.9553	174	868.3958	237	1075.489
49	491.9941	112	675.9665	175	871.592	238	1078.87
50	494.8233	113	678.9807	176	874.7911	239	1082.254
51	497.6554	114	681.9978	177	877.9932	240	1085.641
52	500.4904	115	685.0178	178	881.1982	241	1089.031
53	503.3284	116	688.0408	179	884.4061	242	1092.424
54	506.1693	117	691.0667	180	887.617	243	1095.82
55	509.0132	118	694.0955	181	890.8307	244	1099.219
56	511.86	119	697.1272	182	894.0475	245	1102.62
57	514.7097	120	700.162	183	897.2672	246	1106.025
58	517.5624	121	703.1996	184	900.4898	247	1109.432
59	520.418	122	706.2402	185	903.7153	248	1112.843
60	523.2766	123	709.2837	186	906.9438	249	1116.256
61	526.138	124	712.3301	187	910.1752	250	1119.673
62	529.0024	125	715.3795	188	913.4095	251	1123.092
63	531.8698	126	718.4318	189	916.6468	252	1126.514

For 1996: Wavelengths, in nanometers, and their corresponding channels, used for data reduction. Wavelength Characterization (nm) for BOREAS TE-10 SE590 on 19-May-1996 by NASA GSFC (SE590 serial number 1051):

ch.	wavelength	ch.	wavelength	ch.	wavelength	ch.	wavelength
1	360.1405	64	535.3193	127	722.5816	190	921.0249
2	362.9569	65	537.9889	128	725.6702	191	923.5632
3	366.4362	66	541.1645	129	727.8751	192	926.5912
4	369.2162	67	543.9707	130	730.7025	193	931.4050
5	370.6827	68	546.2993	131	734.3596	194	934.4142
6	373.5435	69	549.7904	132	737.8586	195	936.2727
7	376.1163	70	552.4260	133	740.2515	196	939.8535
8	378.7204	71	555.3782	134	743.3154	197	942.9930
9	382.4035	72	558.2172	135	747.1053	198	947.1103
10	385.6378	73	561.9365	136	750.4144	199	949.8366
11	387.9678	74	564.9579	137	752.2017	200	952.7264
12	389.4546	75	567.6845	138	755.3228	201	956.8641
13	392.1760	76	569.5253	139	759.0406	202	959.8645
14	395.1965	77	573.2707	140	763.4584	203	963.1107
15	397.7772	78	575.2397	141	764.6765	204	967.0283
16	400.4819	79	579.1161	142	768.4408	205	969.6374
17	403.0910	80	581.6889	143	771.3158	206	973.4302
18	406.1777	81	585.3271	144	774.3496	207	976.1201
19	409.4557	82	587.1065	145	777.1546	208	978.8361
20	411.9212	83	590.0847	146	781.1493	209	983.2477
21	414.6198	84	594.0846	147	784.5945	210	985.5351
22	417.5016	85	596.4154	148	786.4127	211	990.1134
23	420.2417	86	598.7330	149	789.8508	212	993.0454
24	423.4704	87	601.8935	150	792.8632	213	995.8198
25	426.7591	88	604.8884	151	795.7158	214	999.0036
26	429.4513	89	608.6492	152	800.2796	215	1002.6315
27	430.5617	90	610.9973	153	802.2711	216	1005.7451
28	433.8799	91	613.6475	154	805.7332	217	1009.4871
29	436.2423	92	617.6015	155	809.1172	218	1013.0036
30	439.8257	93	619.5585	156	811.5326	219	1015.9353
31	442.8191	94	622.6438	157	815.6465	220	1019.1051
32	445.1902	95	625.6931	158	817.9621	221	1021.9994
33	447.2221	96	629.0358	159	821.7254	222	1025.8942
34	450.4475	97	631.4492	160	824.7415	223	1028.6137
35	453.6972	98	634.8992	161	828.5148	224	1032.6801
36	455.8462	99	637.0956	162	830.6718	225	1035.4542
37	458.9906	100	640.1055	163	834.1582	226	1038.6841
38	462.2092	101	643.4478	164	837.6238	227	1042.0068
39	465.0868	102	646.6421	165	840.2246	228	1045.3784
40	467.5963	103	649.7776	166	842.9457	229	1049.1268
41	469.4833	104	651.9899	167	847.2484	230	1051.9782
42	472.7325	105	655.1663	168	849.3214	231	1055.3909
43	475.9141	106	659.8316	169	852.6053	232	1059.2382
44	479.0778	107	661.3675	170	856.0376	233	1063.5007
45	480.9206	108	664.0426	171	859.6738	234	1066.2681
46	483.5598	109	667.6396	172	863.4929	235	1068.9670
47	487.3832	110	670.2188	173	865.7373	236	1073.9716
48	489.9419	111	673.0377	174	868.4055	237	1075.6882

49	492.1505	112	677.4711	175	872.3803	238	1079.6127
50	495.6179	113	679.6326	176	875.2328	239	1083.1027
51	497.7992	114	682.0668	177	879.0570	240	1086.6284
52	500.9829	115	686.0143	178	881.4289	241	1089.3537
53	504.4008	116	688.6492	179	885.2314	242	1092.7966
54	506.7443	117	691.6828	180	888.7613	243	1096.3125
55	509.7821	118	694.6542	181	892.0937	244	1099.3362
56	512.6732	119	698.4924	182	895.2754	245	1104.0854
57	514.8358	120	700.9617	183	897.2797	246	1106.1711
58	518.5168	121	703.7869	184	901.5139	247	1109.6832
59	520.9057	122	706.4359	185	903.9839	248	1113.4952
60	524.6469	123	709.6463	186	907.1931	249	1117.2942
61	526.8958	124	712.4398	187	910.2802	250	1120.0276
62	529.1754	125	716.6992	188	913.4571	251	1123.8413
63	532.3863	126	719.1289	189	916.9567	252	1127.0125

5. Data Acquisition Methods

Measurements were made on aspen and hazelnut leaves obtained from the upper and lower canopy layers of the tree overstories. At the sites, branches were accessed from canopy access towers erected by BOREAS staff. Stray light was measured at the beginning of each day and/or with each light source used. The color of the leaves was coded using the Munsell color chips (Munsell, 1977) prior to optical measurements. The method of sample measurement is described below:

The sample element filled the integrating sphere sample port. Procedures for optical property measurements are described by Daughtry et al. (1989). Individual leaves or stems were cut from the plant. The needles remained attached to the stem during the measurement. Each leaf or needles measured was inserted into the integrating sphere sample port with the adaxial (top) surface facing the inside of the sphere. Three measurements followed:

- light reflected from the reference for the adaxial surface
- light reflected from the adaxial surface
- light transmitted through the abaxial (bottom) surface

The sample was removed from the sample port and reinserted so that the abaxial surface faced the inside of the sphere; the sample was arranged so that the same portion of the sample was measured. Three additional measurements followed:

- light transmitted through the adaxial surface
- light reflected from the abaxial surface
- light reflected from the reference for the abaxial surface

All samples were illuminated with the standard external light source. Because of the difficulty in measuring needle samples, some transmittance values in the visible spectrum were calculated to be negative and were not indicative of true values. The methodology used for correcting the transmittance values is given in Section 9.1.1. For further information and indepth explanation regarding transmittance correction technique, please refer to Middleton et al. (IGARSS 1996).

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

None given.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

Samples were taken from the top, middle, and bottom of the canopy as indicated in the CANOPY_LOCATION parameter in the data sets. The OJP, OA, and OBS samples were obtained with the aid of canopy access towers located at the OJP, OA, OA-AUX, and OBS sites. The SSA measurement sites and associated North American Datum of 1983 (NAD83) coordinates are:

- OBS canopy access tower located at the flux tower site, site id G8I4T, Lat/Long: 53.98717 N, 105.11779 W, Universal Transverse Mercator (UTM) Zone 13, N:5,982,100.5 E;492,276.5.
- OA canopy access tower located 100 m up the path to the flux tower site, site id C3B7T, Lat/Long: 53.62889 N, 106.19779 W, UTM Zone 13, N:5,942,899.9 E:420,790.5.
- OA-AUX was the canopy access tower located by the trailhead/parking area for the path leading to the flux tower at site id C3B7T, Lat/Long: 53.62889 N, 106.19779 W, UTM Zone 13, N:5,942,899.9 E:420,790.5. This SSA-OA-AUX site was farther up the path than SSA-OA from the flux tower site.
- OJP canopy access tower flux tower site, site id G2L3T, Lat/Long: 53.91634 N, 104.69203 W, UTM Zone 13, N:5,974,257.5 E:520,227.7.
- YA canopy access tower, site id D0H4T, Lat/Long: 53.65601 N, 105.32314 W, UTM Zone 13, N:5,945,298.9, E:478,644.1.
- YJP near flux tower site, site id F8L6T, Lat/Long: 53.87581 N, 104.64529 W, UTM Zone 13, N:5,969,762.5 E:523,320.2.
- YA-AUX site id D6H4A, Lat/Long: 53.708 N, 105.315 W, UTM Zone 13, N: 5,951,112.1 E: 479,177.5 near the Snow Castle Lodge.

Please note that at YA-AUX black spruce, jack pine, aspen, balsam fir, balsam poplar, tamarack, hazelnut, and several other shrub and herbaceous species were also present.

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

The measurements were obtained from single leaves and needles collected from sample trees near the coordinates given in Section 7.1.1.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

Preparation for measurement took 5 minutes per broadleaf sample and 10 minutes per conifer sample. The measurements for each sample took under 5 minutes. Samples were stored for 2 to 3 hours in the refrigerator.

7.2.1 Temporal Coverage

In 1994, data were collected from 24-May to 15-Sep. In 1996, data were collected from 11-Jul to 16-Jul.

7.2.2 Temporal Coverage Map

Samples were collected from 8:00 a.m. to 3:00 p.m. on the following days in 1994:

Site	IFC-1	IFC-2	IFC-3
SSA-OBS	02-Jun-1994	29-Jul-1994	15-Sep-1994
SSA-OJP	01-Jun-1994	23-Jul-1994	08-Sep-1994
SSA-YJP	28-May-1994	23-Jul-1994	09-Sep-1994
SSA-YA-AUX	N/A	31-Jul-1994	12-Sep-1994
SSA-OA	24-May-1994 29-May-1994 09-Jun-1994	20-Jul-1994	14-Sep-1994
SSA-YA	25-May-1994 03-Jun-1994	29-Jul-1994	01-Sep-1994 11-Sep-1994
SSA-OA-AUX	N/A	20-Jul-1994	01-Sep-1994

For 1996: Samples were collected from 8:00 a.m. to 3:00 p.m. on the following days in 1996:

Site	Dates
SSA-OBS	15-Jul-1996
SSA-OJP	12-Jul-1996
SSA-YJP	13-Jul-1996 and 16 Jul-1996
SSA-YA-AUX	11-Jul-1996

7.2.3 Temporal Resolution

None given.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The parameters contained in the data files on the CD-ROM are:

Column Name
SITE_NAME
SUB_SITE
DATE_OBS
SPECIES
SAMPLE_GROWTH_YEAR
CANOPY_LOCATION
NUM_OBS
WAVELENGTH
MEAN_ADAXIAL_REFL
SDEV_ADAXIAL_REFL
MEAN_ADAXIAL_TRANS
SDEV_ADAXIAL_TRANS
MEAN_ABAXIAL_REFL
SDEV_ABAXIAL_REFL
MEAN_ABAXIAL_TRANS
SDEV_ABAXIAL_TRANS
CRTFCN_CODE
REVISION_DATE

7.3.2 Variable Description/Definition

The descriptions of the parameters contained in the data files on the CD-ROM are:

Column Name	Description
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument, e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.
DATE_OBS	The date on which the data were collected.
SPECIES	Botanical (Latin) name of the species (Genus species).
SAMPLE_GROWTH_YEAR	The year in which the collected sample first grew.
CANOPY_LOCATION	Location in the canopy from which the sample was taken.
NUM_OBS	Number of observations of the given sample used to calculate given values.
WAVELENGTH	Spectral wavelength at which measurement was acquired.
MEAN_ADAXIAL_REFL	The mean reflectance of the adaxial surface of sample.
SDEV_ADAXIAL_REFL	Standard deviation of reflectance of the adaxial surface of sample.
MEAN_ADAXIAL_TRANS	The mean transmittance of the adaxial surface of the sample. The adaxial surface was illuminated during measurements.
SDEV_ADAXIAL_TRANS	Standard deviation of transmittance through the adaxial surface of sample.
MEAN_ABAXIAL_REFL	Mean reflectance of the abaxial surface of sample.
SDEV_ABAXIAL_REFL	Standard deviation of reflectance of the abaxial surface of sample.
MEAN_ABAXIAL_TRANS	The mean transmittance of the abaxial surface of the sample. The abaxial surface was illuminated during measurements.
SDEV_ABAXIAL_TRANS	Standard deviation of reflectance through the abaxial surface of sample.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).
REVISION_DATE	The most recent date when the information in the referenced data base table record was revised.

7.3.3 Unit of Measurement

The measurement units for the parameters contained in the data files on the CD-ROM are:

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
DATE_OBS	[DD-MON-YY]
SPECIES	[none]
SAMPLE_GROWTH_YEAR	[unitless]
CANOPY_LOCATION	[none]
NUM_OBS	[counts]
WAVELENGTH	[micrometers]
MEAN_ADAXIAL_REFL	[percent]
SDEV_ADAXIAL_REFL	[percent]
MEAN_ADAXIAL_TRANS	[percent]
SDEV_ADAXIAL_TRANS	[percent]
MEAN_ABAXIAL_REFL	[percent]
SDEV_ABAXIAL_REFL	[percent]
MEAN_ABAXIAL_TRANS	[percent]
SDEV_ABAXIAL_TRANS	[percent]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

7.3.4 Data Source

The sources of the parameter values contained in the data files on the CD-ROM are:

Column Name	Data Source
SITE_NAME	[BORIS Designation]
SUB_SITE	[BORIS Designation]
DATE_OBS	[Human Observer]
SPECIES	[Human Observer]
SAMPLE_GROWTH_YEAR	[Human Observer]
CANOPY_LOCATION	[Human Observer]
NUM_OBS	[Human Observer]
WAVELENGTH	[Laboratory Equipment]
MEAN_ADAXIAL_REFL	[Laboratory Equipment]
SDEV_ADAXIAL_REFL	[Laboratory Equipment]
MEAN_ADAXIAL_TRANS	[Laboratory Equipment]
SDEV_ADAXIAL_TRANS	[Laboratory Equipment]
MEAN_ABAXIAL_REFL	[Laboratory Equipment]
SDEV_ABAXIAL_REFL	[Laboratory Equipment]
MEAN_ABAXIAL_TRANS	[Laboratory Equipment]
SDEV_ABAXIAL_TRANS	[Laboratory Equipment]
CRTFCN_CODE	[BORIS Designation]
REVISION_DATE	[BORIS Designation]

7.3.5 Data Range

The following table gives information about the parameter values found in the data files on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missing Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	SSA-9OA-FLXTR	SSA-YJP-FLXTR	None	None	None	None
SUB_SITE	9TE10-LFO01	9TE10-LFO02	None	None	None	None
DATE_OBS	25-MAY-94	14-JUL-96	None	None	None	None
SPECIES	N/A	N/A	None	None	None	None
SAMPLE_GROWTH_YEAR	1988	1996	None	None	None	None
CANOPY_LOCATION	Bottom	Top	None	None	None	None
NUM_OBS	1	17	None	None	None	None
WAVELENGTH	.400	1.000	None	None	None	None
MEAN_ADAXIAL_REFL	3.572	75.46	None	None	None	None
SDEV_ADAXIAL_REFL	0	14.867	-999	None	None	None
MEAN_ADAXIAL_TRANS	-.03	61.856	None	None	None	None
SDEV_ADAXIAL_TRANS	0	16.938	-999	None	None	None
MEAN_ABAXIAL_REFL	3.59	75.2	None	None	None	None
SDEV_ABAXIAL_REFL	0	12.409	-999	None	None	None
MEAN_ABAXIAL_TRANS	0	64.044	None	None	None	None
SDEV_ABAXIAL_TRANS	0	17.556	-999	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	22-JUL-98	24-JUL-98	None	None	None	None

Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missing Data Value -- The value that indicates missing data. This is used to indicate that an attempt was made to determine the parameter value, but the attempt was unsuccessful.
Unrel Data Value -- The value that indicates unreliable data. This is used to indicate an attempt was made to determine the parameter value, but the value was deemed to be unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the instruments detection limits. This is used to indicate that an attempt was made to determine the parameter value, but the analysis personnel determined that the parameter value was below the detection limit of the instrumentation.
Data Not Cllctd -- This value indicates that no attempt was made to determine the parameter value. This usually indicates that BORIS combined several similar but not identical data sets into the same data base table but this particular science team did not measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A -- Indicates that the value is not applicable to the respective column.
None -- Indicates that no values of that sort were found in the column.

7.4 Sample Data Record

The following are wrapped versions of data record from a sample data file on the CD-ROM.

```
SITE_NAME,SUB_SITE,DATE_OBS,SPECIES,SAMPLE_GROWTH_YEAR,CANOPY_LOCATION,NUM_OBS,
WAVELENGTH,MEAN_ADAXIAL_REFL,SDEV_ADAXIAL_REFL,MEAN_ADAXIAL_TRANS,
SDEV_ADAXIAL_TRANS,MEAN_ABAXIAL_REFL,SDEV_ABAXIAL_REFL,MEAN_ABAXIAL_TRANS,
SDEV_ABAXIAL_TRANS,CRTFCN_CODE,REVISION_DATE
'SSA-9OA-FLXTR','9TE10-LFO01',25-MAY-94,'Corylus cornuta','1994','Upper',10,.400,
3.988,1.04,2.813,.831,4.603,.839,2.917,.854,'CPI',23-JUL-98
'SSA-9OA-FLXTR','9TE10-LFO01',25-MAY-94,'Corylus cornuta','1994','Upper',10,.405,
4.073,.491,2.64,.859,5.243,.717,2.842,.649,'CPI',23-JUL-98
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by the BOREAS Information System (BORIS) was the data collected at a given site on a given date.

8.2 Data Format(s)

The Compact Disk-Read-Only Memory (CD-ROM) files contain American Standard Code for Information Interchange (ASCII) numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

Each data file on the CD-ROM has four header lines of Hyper-Text Markup Language (HTML) code at the top. When viewed with a Web browser, this code displays header information (data set title, location, date, acknowledgments, etc.) and a series of HTML links to associated data files and related data sets. Line 5 of each data file is a list of the column names, and line 6 and following lines contain the actual data.

9. Data Manipulations

9.1 Formulae

In the formulas below, for leaf samples, the leaf would cover the whole area of the aperture resulting in a zero gap fraction and negating that term in the equation.

For 1994, these formulae were used for both conifers and broadleafs:

$$\text{reflectance} = \frac{(Fr-Fn)}{(Fwr-Fn)} * \frac{Rr}{G3} \qquad [1]$$

$$\text{transmittance} = \frac{Ft}{(Fwt-Fn)} * \frac{Rr}{G3} \qquad [2]$$

where: Fr = flux measured in reflectance mode
Ft = flux measured in transmittance mode
Fn = flux measured in reflectance mode with no sample
Fwr, Fwt = flux measured in reference mode for side of leaf illuminated during eflectance and transmittance measurements, respectively
Rr = reflectance of $BaSO_4$ reference surface
G3 = function of sphere reflectance and geometry and sample reflectance

For 1996, these formulae were used for both conifers and broadleafs:

REFLECTANCE

Adaxial: $$RC(top)=\left[\frac{(RT-STR)}{(RFT-STR)}\right]*\frac{1}{(1-GF)}*100 \qquad [3]$$

Abaxial: $$RC(bottom)=\left[\frac{(RB-STR)}{(RFB-STR)}\right]*\frac{1}{(1-GF)}*100 \qquad [4]$$

TRANSMITTANCE

Adaxial: $$TC(top)=\left[\frac{TT}{(RFB-STR)} - \frac{w*GF}{(X-STR)}\right]*\frac{1}{(1-GF)}*100 \qquad [5] \text{ (Old Formula)}$$

$$TC(top)=\left\{\frac{TT}{(RFB-STR)} - \left[\frac{w*GF}{(X-STR)}\right]^{2}\right\}*100 \qquad [6] \text{ (Revised Formula)}$$

$$TC(top)=\left\{\frac{TT}{(RFB-STR)} - \left[\frac{w*GF}{(X-STR)}\right]^{2}\right\}*\frac{1}{(1-GF)}*100 \qquad [7] \text{ (Revised Formula-2)}$$

Abaxial: $$TC(bottom)=\left[\frac{TB}{(RFT-STR)} - \frac{w*GF}{(X-STR)}\right]*\frac{1}{(1-GF)}*100 \qquad [8] \text{ (Old Formula)}$$

$$TC(bottom)=\left\{\frac{TB}{(RFT-STR)} - \left[\frac{w*GF}{(X-STR)}\right]^{2}\right\}*100 \qquad [9] \text{ (Revised Formula)}$$

$$TC(bottom)=\left\{\frac{TB}{(RFT-STR)} - \left[\frac{w*GF}{(X-STR)}\right]^{2}\right\}*\frac{1}{(1-GF)}*100 \qquad [10] \text{ (Revised Formula-2)}$$

where: GF gap fraction
RC corrected reflectance
RFB observed reference standard bottom (adaxial)
RFT observed reference standard top (abaxial)
RB observed reflectance bottom (side of needle surface)
RT observed reflectance top (side of needle surface)
STR observed stray light in reflectance mode
TC corrected transmittance
TB observed transmittance bottom (side of needle surface)
TT observed transmittance top (side of needle surface)
w observed sphere wall reflectance

9.1.1 Derivation Techniques and Algorithms

The corrected transmittance is a function of three parameters: the original calculated transmittance, gap fraction, and slope.

CALIBRATION DATA SET

In order to obtain values for the slope parameter, calibration data sets of conifer needles were taken in 1994 and 1996 at the sites in the SSA, located in the general vicinities of Candle Lake and Nipowan, Saskatchewan, Canada. Optical properties of the needles were then measured with varying gap fractions. Calibration data sets were compiled using gap fractions varying from approximately 0%-45%. The spectral regions associated with the greatest absorption (e.g., chlorophyll) were found to be most affected: negative transmittances were calculated in the visible for virtually all gap fractions, for these needles.

GAP FRACTION

Unlike broadleaves, conifer needles are unable to occupy the entire aperture of the measuring device. Therefore, a certain percentage of energy is allowed to pass beyond the sample to the measuring device, without being disturbed by the physical properties of the needle. This percentage is the gap fraction parameter, which is the percentage of aperture uncovered by needles. Gap fraction was calculated for all the conifer needle samples. Preliminary analysis suggested that the effect of the gap fraction on leaf optical properties was a function of energy wavelength. In other words, gap fraction affected properties at higher percentages in the visible spectrum than in the near-infrared spectrum, implying the need for another parameter.

SLOPE for 1994

In order to obtain values for the slope parameter, a calibration data set of conifer needles was taken at sites in the SSA. Optical properties of the needles were then measured with varying gap fractions and similar techniques as used for the three IFCs. The spectral regions associated with the greatest absorption (e.g., chlorophyll) were found to be most affected: negative transmittance were calculated in the visible for virtually all gap fractions, for these needles. The measured transmittance is linearly related to gap fraction, and the regression coefficients of these relationships was used as the slope parameter.

SLOPE for 1996

Slope is calculated by using the transmittance data from the calibration data sets. The measured transmittance is linearly related to gap fraction, and the regression coefficients of these relationships was used as the slope parameter. It was deemed unnecessary to use any correction below a 17% gap fraction.

CORRECTED TRANSMITTANCE

The corrected transmittance values were then calculated as the product of gap fraction and slope, subtracted from the original calculated transmittance.

$$(\text{Corrected T}) = (\text{Measured T}) - (\text{Gap Fraction} * \text{Slope}) \qquad [11]$$

9.2 Data Processing Sequence

9.2.1 Processing Steps

None given.

9.2.2 Processing Changes

None given.

9.3 Calculations

None given.

9.3.1 Special Corrections/Adjustments

Because different procedures were used in 1996 by the instrument operator, a correction was applied to the 1996 black spruce data to make them consistent with all the other data collected in 1994 and 1996. During all but the 1996 black spruce collection sessions, the integrating sphere was empty during referencing procedures. In 1996, an empty sample holder was in place on the integrating sphere at all times, including when the initial reference measurements were made.

Having the empty sample holder in place during the initial referencing procedures in the 1996 black spruce sessions resulted in a reduction of black spruce reflectance values. This affected the black spruce data due to the very small needle size which necessitated the use of the sample holder with the slitted aperture. To normalize the 1996 black spruce data with the other data collected in 1994 and 1996, an offset value was calculated by using a ratio of stray light from the wall (STRW) to the stray light from the sample (STRS), which was then applied to the data. The offset value for black spruce was calculated by:

```
(STRW/STRS ratio of 1996 jack pine data)
------------------------------------------ = offset for 1996 black spruce data [12]
(STRW/STRS ratio of 1996 black spruce data)
```

9.3.2 Calculated Variables

None given.

9.4 Graphs and Plots

None given.

10. Errors

10.1 Sources of Error

During the 1996 summer collection session, a slightly different data acquisition methodology was used which resulted in a reduction of black spruce reflectance values. An empty sample holder was in place within the integrating sphere at all times, including during the initial reference-taking steps. Previously, the sample holder was absent while referencing. This affected only the black spruce data because of the very small needle size, which necessitated the use of the sample holder with the slitted aperture. To normalize the 1996 summer session black spruce data with the other data from 1994 and 1996, an offset value was calculated by using a ratio of the STRW/STRS from the 1996 black spruce data and the STRW/STRS from the 1996 jack pine data, which was then applied to the data. The offset was calculated using:

```
(STRW/STRS ratio of 1996 jack pine data)
------------------------------------------ = offset for 1996 black spruce data [12]
(STRW/STRS ratio of 1996 black spruce data)
```

10.2 Quality Assessment

10.2.1 Data Validation by Source

Comparisons were made with other BOREAS results and with published results.

10.2.2 Confidence Level/Accuracy Judgment

In 1994, the methods used during IFC-1 produced some minor distortions in the data that were not totally eliminated by postcollection processing, resulting in an 80% confidence level in IFC-1 data. Revisions in techniques and streamlining of sample collection and measurement methods were implemented as needed. These occurred mainly during IFC-1, which acted as TE-10's learning phase. Therefore, confidence in IFC-2 and IFC-3 data is much stronger, with a degree of reliability greater than 90%.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

Calculated results were plotted, and the plots were compared with those from published papers.

10.2.5 Data Verification by Data Center

Data were examined for general consistency and clarity.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

Because of the difficulty in measuring needle samples, some transmittance values in the visible spectrum measured negative and were not indicative of true values.

11.3 Usage Guidance

None given.

11.4 Other Relevant Information

In 1996, the small size and quantity of black spruce needles present on the trees sampled, because of low production, necessitated combining two age classes of needles in several instances to achieve a large enough sample size.

Acknowledgment of other research staff who assisted in this study: Scott K. Mitchell, UMD Undergraduate Student; Robert J. Rusin, UMD Undergraduate Student; David A. Shirey, UMD Graduate Student

12. Application of the Data Set

This data set will be of interest to investigators undertaking data comparisons and integrations, and parameterization or validation of canopy models requiring leaf-level optical information at these and similar sites.

13. Future Modifications and Plans

None given.

14. Software

14.1 Software Description

Computer Eyes /RT (Digital Vision, Inc., Dedham, MA) Custom software developed by M.A. Mesarch of UNL Excel 5.0 for Windows (Microsoft) Mocha (SPSS, Inc., Chicago, IL) Systat 6.0 (SPSS, Inc., Chicago, IL)

14.2 Software Access

None given.

15. Data Access

The leaf optical properties data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

None.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

LI-COR LI-1800-12 Integrating Sphere Instruction Manual. 1983. Pub. No. 8305-0034. LI-COR, Inc., Lincoln, NE.

Spectron Engineering, Inc. Operating Manual: SE590 field portable data-logging spectroradiometer, Serial Number Spectron Engineering, Denver, CO 80223.

17.2 Journal Articles and Study Reports

Daughtry, C.S.T., L.L. Biehl, and K.J. Ranson. 1989. A new technique to measure the spectral properties of conifer needles. Remote Sensing Environment 27:81-91.

Esau, K. 1977. Anatomy of Seed Plants, 2nd ed. John Wiley & Sons, New York, 550 pp.

Mesarch, M.A. et al. 1998. A Revised Measurement Methodology for Conifer Needles Spectral Properties: Evaluating the Influence of Gaps Between Elements. Remote Sensing Review (submitted 1998).

Middleton, E.M. et al. 1996. A Revised Measurement Methodology for Spectral Optical Properties of Conifer Needles. As presented for Proceedings, 1996 International Geoscience and Remote Sensing Symposium (IGARSS '96).

Middleton, E.M., S.S. Chan, R.J. Rusin, and S.K. Mitchell. 1997. Optical Properties of Black Spruce and Jack Pine needles at BOREAS sites in Saskatchewan, Canada. Canadian Journal of Remote Sensing. vol. 23, no. 2, pp. 108-119.

Munsell Color (Firm). 1977. Munsell Color Charts for Plants Tissues. 2nd ed. Munsell Color (Firm), Baltimore, MD, 6 pp. 17 color charts.

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Norman, J.M. and P.G. Jarvis. 1974. Photosynthesis in Stika Spruce [Picea Sitchenis (Bong.) Carr.] III. Measurements of canopy structure and interception of radiation. J. Appl. Ecol. 11:375-398.

Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment Overview, Scientific Results and Future Directions. Journal of Geophysical Research 102(D24): 28,731-28,770.

Smith, W.K. and G.A. Carter. 1988. Shoot structural effects on needle temperatures and photosynthesis in conifers. Amer. J. of Bot. 75:496-500.

Wickland, D. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Williams, D.L. 1991. A comparison of spectral reflectance properties at the needle branch and canopy level for selected conifer species. Remote Sensing Environment 35:79-93.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

Abaxial: The ventral or underside of leaf or needle.
Adaxial: The dorsal or upper of leaf or needle.
Channel (ch): One band on the SE590, each having a unique wavelength.
Gap fraction: The percentage of aperture not covered by needles.
Reflectance (R): Light shines on the specified surface, bounces off this surface, and then bounces around in the integrating sphere; the spectroradiometer then measures the integrated light that is bouncing around in the sphere.
STRS: Stray light from the sample.
STRW: Stray light from the wall.
Transmittance (T): Light shines on the specified surface, goes through the needle, and then passes into the integrating sphere; the spectroradiometer then measures the integrated light that is bouncing around in the sphere.

19. List of Acronyms

ASCII - American Standard Code for Information Interchange
B/W - Black and White
BOREAS - BOReal Ecosystem-Atmosphere Study
BORIS - BOREAS Information System
CCD - Charge-Coupled Device
CD-ROM - Compact Disk-Read-Only Memory
DAAC - Distributed Active Archive Center
EOS - Earth Observing System
EOSDIS - EOS Data and Information System
fAPAR - fraction of Absorbed Photosynthetically Active Radiation
GF - Gap Fraction
GIS - Geographic Information System
GMT - Greenwich Mean Time
GSFC - Goddard Space Flight Center

```
HTML     - HyperText Markup Language
IFC      - Intensive Field Campaign
IGARSS   - International Geoscience And Remote Sensing Symposium
NAD83    - North American Datum of 1983
NASA     - National Aeronautics and Space Administration
NDVI     - Normalized Difference Vegetation Index
NSA      - Northern Study Area
OA       - Old Aspen
OA-AUX   - Old Aspen Auxiliary
OBS      - Old Black Spruce
OJP      - Old Jack Pine
ORNL     - Oak Ridge National Laboratory
PANP     - Prince Albert National Park
PAR      - Photosynthetically Active Radiation
SSA      - Southern Study Area
STDEV    - Standard Deviation
SVI      - Spectral Vegetation Index
TE       - Terrestrial Ecology
URL      - Uniform Resource Locator
UTM      - Universal Transverse Mercator
WS       - White Spruce
YA       - Young Aspen
YA-AUX   - Young Aspen Auxiliary
YJP      - Young Jack Pine
```

20. Document Information

20.1 Document Revision Date
Written: 26-Jun-1997
Last updated: 10-Aug-1999

20.2 Document Review Date(s)
BORIS Review: 15-Jul-1998
Science Review: 06-Aug-1998

20.3 Document ID

20.4 Citation
When using these data, please include the following acknowledgment as well as citations of relevant papers in Section 17.2:

S.S. Chan and E M. Middleton Biospheric Sciences Branch, Code 923 NASA GSFC

If using data from the BOREAS CD-ROM series, also reference the data as:

Middleton, E. and J. Sullivan, "CO_2 and Water Fluxes in the Boreal Forest Overstory: Relationship to fAPAR and Vegetation Indices for Needles/Leaves." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

Also, cite the BOREAS CD-ROM set as:
Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM. NASA, 2000.

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 2000

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS TE-10 Leaf Optical Properties

5. FUNDING NUMBERS
923
RTOP: 923-462-33-01

6. AUTHOR(S)
Stephen .S. Chan and Elizabeth Middleton
Forrest G. Hall and Andrea Papagno, Editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)
Goddard Space Flight Center
Greenbelt, Maryland 20771

8. PEFORMING ORGANIZATION REPORT NUMBER
2000-03136-0

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS (ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001 .

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
TM—2000–209891
Vol. 162

11. SUPPLEMENTARY NOTES
A. Papagno: Raytheon ITSS, NASA Goddard Space Flight Center, Greenbelt, Maryland

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category: 43
Report available from the NASA Center for AeroSpace Information,
7121 Standard Drive, Hanover, MD 21076-1320. (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The BOREAS TE-10 team collected several data sets in support of its efforts to characterize and interpret information on the reflectance, transmittance, gas exchange, oxygen evolution, and biochemical properties of boreal vegetation. This data set describes the spectral optical properties (reflectance and transmittance) of boreal forest conifers and broadleaf tree leaves as measured with a Spectron Engineering SE590 spectroradiometer at the SSA OBS, OJP, YJP, OA, OA-AUX, YA-AUX, and YA sites. The data were collected during the growing seasons of 1994 and 1996 and are stored in tabular ASCII files.

14. SUBJECT TERMS
BOREAS, terrestrial ecology, boreal vegetation.

15. NUMBER OF PAGES
24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39.18
298-102